



GUIDANCE NOTES ON

ALTERNATIVE DESIGN AND ARRANGEMENTS FOR FIRE SAFETY

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Foreword

Background

Fire safety regulations can have a major impact on many aspects of the overall design of ships, including design layout, aesthetics, function, costs, etc. Rapid developments in modern shipbuilding technology have often resulted in unconventional structures and design solutions. As the physical size of ships continuously increases, the complexity of design and functionality also increases. At the same time, there have been great strides in understanding of fire processes and their interrelationship with humans and ships. Advancement has been particularly rapid in the areas of analytical fire modeling. Several different types of such models, with varying degrees of sophistication, have been developed in recent years and are used by engineers in the design process.

The SOLAS regulation II-2/Regulation 17, “Alternative design and arrangements”, along with supporting MSC/Circ. 1002 entered into force on July 1, 2002, allows a methodology to be used for alternative design and arrangements for fire safety. It essentially permits the use of a performance-based fire engineering approach to achieve an equivalent level of safety to the prescriptive requirements for all ship types. This approach focuses on the overall performance of specific arrangements and their ability to meet the fire safety objectives, enabling enhanced flexibility in ship design and allowing for arrangements which traditionally had not been permitted within the prescriptive framework.

As a result, the ship design is no longer restricted to the predefined conditions within the regulations. The fire safety measures can now be chosen to address the specific hazards present in each ship. Instead of prescribing exactly which protective measures are required, the performance of the overall system is presented against a specified set of design objectives (such as stating that satisfactory escape should be affected in the event of fire). Fire modeling and evacuation modeling can often be used to assess the effectiveness of the proposed protective measures.

MSC/Circ. 1002, “Guidelines on Alternative Design and Arrangements for Fire Safety”, outline the methodology for the engineering analysis required by SOLAS regulation II-2/17, applying to a specific fire safety system, design or arrangements for which the approval of an alternative design deviating from prescriptive requirements of SOLAS Chapter II-2 is sought.

However, in MSC/Circ. 1002, little information has been provided for some crucial parts of fire safety analysis, for example, how to develop the performance criteria and how to select the hazard for analysis. In fact, designers and shipbuilders need the processing guidance on how to carry out the procedures addressed in MSC/Circ. 1002.

In response to industry need, ABS has developed these *Guidance Notes on Alternative Design and Arrangements for Fire Safety* in order to assist in the understanding of MSC/Circ. 1002. These Guidance Notes not only encapsulate the entire contents of MSC/Circ. 1002, but also provide supplemental materials to further explain the guidelines in MSC/Circ. 1002, in particular, in the areas of identifying design fire scenarios, developing trials, selecting design tools for trial alternative designs and developing performance-based criteria, etc. Therefore, these Guidance Notes provide a practical methodology for the situations where an alternative design is being proposed on the premise that it provides the equivalent level of safety to the SOLAS regulations.

Contents of the Guidance Notes

These Guidance Notes follow the section numbering of MSC/Circ. 1002 and provide explanatory appendices for the issues addressed in those sections. The contents of the Guidance Notes take the following order:

Section 1: Application. The purpose and the scope of application of these Guidance Notes are addressed in this Section.

Section 2: Definitions. This Section defines the general terms used with specific technical meanings in these Guidance Notes for the purpose of clarification. Some terms which are not listed in MSC/Circ. 1002, but used in these Guidance Notes, are listed in a separate order.

Section 3: Engineering Analysis. This Section emphasizes the necessity of following an established approach for the process of the alternative design and arrangements. This Section also provides two examples of established approaches, and defines the proper phases of process, i.e., preliminary analysis and quantitative analysis.

Section 4: Design Team. This Section emphasizes the qualification and the responsibility of the design team acceptable to the Administration.

Section 5: Preliminary Analysis in Qualitative Terms. The process of preliminary analysis is outlined in detail in this Section. The Subsections contain a great deal of explanatory material to supplement the original section of MSC/Circ. 1002 regarding the definition of scope, the development of fire scenarios, the development of trial alternative designs and the preliminary analysis report.

Section 6: Quantitative Analysis. The quantitative analysis is the most labor-intensive from a fire safety engineering standpoint. It consists of quantifying the design fire scenarios, developing the performance criteria, verifying the acceptability of the selected safety margins and evaluating the performance of trial alternative designs against the prescriptive performance criteria. All of these issues are discussed in detail in this Section, and some are further discussed in the corresponding Appendices of these Guidance Notes.

Section 7: Documentation. This Section lists the necessary steps of documentation for all design processes.

Appendix A: Report on the Approval of Alternative Design and Arrangements for Fire Safety. This Appendix shows the official submittal form for the approval of alternative design and arrangements for fire safety.

Appendix B: Document of Approval of Alternative Design and Arrangements for Fire Safety. This Appendix shows the official submittal form for the documentation of alternative design and arrangements for fire safety.

Appendix C: Technical Reference and Resources. This Appendix emphasizes the necessary requirements of reliable technical references and resources. Some examples of the technical references and resources are provided in this appendix.

Appendix D: Identifying Design Fire Scenarios. This Appendix discusses the methodology to provide minimum design fire scenarios for evaluation of alternative design and arrangements. Two types of the probabilistic and deterministic design techniques are reviewed.

Appendix E: Developing Trial Alternative Designs. This Appendix focuses on how to develop trial alternative designs to represent fire protection system design alternatives developed to address design fire scenarios to achieve the previously established performance requirements.

Appendix F: Design Tools for Trial Alternative Designs. This Appendix reviews the fundamentals of fire modeling in quantitative fire analysis. It discusses the basics of fire modeling, major assumptions, heat transfer and fire dynamics, explicabilities and limitations of the fire modeling. The main part of this Appendix is devoted to zone modeling and field (CFD) modeling techniques. The final portion of this Appendix lists some available fire models developed for various fire protection applications.

Appendix G: Developing Performance-based Criteria. This Appendix states the effects of life safety and non-life safety criteria on the development of performance criteria. As the consideration of tenability of life safety becomes increasingly important in fire safety design, the effects of various life-threatening hazards are discussed in this Appendix.

Appendix H: Example Analysis - Alternative Design and Arrangements for Containership Cargo Spaces. This Appendix provides an example of alternative design for a carbon dioxide fire extinguishing system in a containership cargo hold. This Appendix outlines the procedures to complete the design process and gives step-by-step illustrations on how the equivalent level of fire protection provided by alternative design can be met against the prescriptive regulations and requirements.

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GUIDANCE NOTES ON ALTERNATIVE DESIGN AND ARRANGEMENTS FOR FIRE SAFETY

CONTENTS

SECTION 1	Application.....	1
SECTION 2	Definitions.....	3
SECTION 3	Engineering Analysis.....	5
1	Process of Alternative Design and Arrangements	5
2	Examples of Acceptable Approaches	5
3	Phases of Process	5
SECTION 4	Design Team.....	7
1	General Requirements	7
2	Qualifications	7
3	Responsibility of Design Team	7
4	Setting the Comparison	8
SECTION 5	Preliminary Analysis to Qualitative Terms	9
1	Definitions of Scope	9
1.1	Contents of Scope	9
1.2	Documenting Regulations	11
2	Development of Fire Scenarios	11
2.1	General	11
3	Development of Trial Alternative Designs.....	13
4	Preliminary Analysis Report.....	13
4.1	Contents of Report	13
4.2	Submittal of Report	13
TABLE 1	Examples of Fire Safety Goals	10

SECTION 6	Quantitative Analysis	15
1	General	15
1.1	Scope	15
1.2	Risk Assessment	15
2	Quantification of Design Fire Scenarios	15
2.1	Choosing Models for Quantification	15
2.2	Developing Fire Scenarios	17
2.3	Description of Fire Scenarios	17
2.4	Consequences of Fire Scenarios	17
3	Development of Performance Criteria	17
3.1	General.....	17
3.2	Performance Criteria Based Directlyn on SOLAS Chapter II-2	18
3.3	Performance Criteria Developed from a Commonly Used Acceptable Prescriptive Design	18
3.4	Specific Performance Criteria and Safety Margins	19
3.5	Impact on Areas not Specifically Part of the Alternative Design	19
3.6	Evaluation.....	19
4	Evaluation of Trial Alternative Designs	19
4.1	Process Flowchart	19
4.2	Analysis of Trial Design	19
4.3	Level of Engineering Analysis	20
4.4	Final Alternative Design and Arrangements	20
FIGURE 1	Alternative Design and Arrangements Process Flowchart.....	20

SECTION 7	Documentation.....	21
1	Basic Requirements.....	21
1.1	Scope of the Analysis or Design.....	21
1.2	Description of Alternative Design(s) or Arrangement(s)	21
1.3	Results of Preliminary Analysis	22
1.4	Results of Quantitative Analysis	22
2	Documentation of Approval	23
3	Reporting and Approval Forms	23
3.1	Report.....	23
3.2	Documentation	23
4	Reference in SOLAS Certificates	23

APPENDIX 1	Report on the Approval of Alternative Design and Arrangements for Fire Safety	25
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APPENDIX 2	Document of Approval of Alternative Design and Arrangements for Fire Safety	27
-------------------	--	-----------

APPENDIX 3 Technical References and Resources 29

APPENDIX 4 Identifying Design Fire Scenarios 31

1	General	31
2	Identifying Design Fire Scenarios	31
3	Probabilistic Design	32
3.1	Background.....	32
3.2	Basic Probabilistic Techniques.....	33
3.3	Data Required	36
3.4	Common Mode Failures.....	37
4	Deterministic Design	38
4.1	Background.....	38
5	Design Fire Curves	40
6	Design Fire Scenarios in NFPA 101	42

FIGURE 1	Fault Tree and Gate for Case when Lower-level Events are Dependent	35
----------	--	----

FIGURE 2	Fault Tree and Gate for Case when Lower-level Events are Independent.....	36
----------	---	----

FIGURE 3	Event Tree.....	36
----------	-----------------	----

FIGURE 4	Phases of a Design Fire Curve	41
----------	-------------------------------------	----

APPENDIX 5 Developing Trial Alternative Designs.....43

1	General	43
2	Functional Statements, Performance Requirements and Trial Designs	43
3	Subsystems	45
3.1	Fire Initiation and Development.....	45
3.2	Spread, Control and Management of Smoke	45
3.3	Fire Detection and Alarm	46
3.4	Automatic Fire Suppression Systems	46
3.5	Human Behavior and Egress	47
3.6	Passive Fire Protection	47
4	Fire Safety Concept Tree (FSCT).....	48
5	References.....	52

TABLE 1	Examples of Objectives, Functional Statements and Performance Requirements.....	44
---------	---	----

FIGURE 1	Top Gate of FSCT.....	48
----------	-----------------------	----

FIGURE 2	Prevent Fire Ignition Branch of FSCT	49
----------	--	----

FIGURE 3	Logic Symbols Used in FSCT	49
----------	----------------------------------	----

FIGURE 4	Major Branch of Manage Fire Impact	49
----------	--	----

FIGURE 5	Manage Fire Branch of FSCT	50
----------	----------------------------------	----

FIGURE 6	Manage Exposed Branch of FSCT	51
----------	-------------------------------------	----

FIGURE 7	Fire Prevent in a Computer Facility.....	51
FIGURE 8	Administration Action Guide.....	52

APPENDIX 6 Design Tools for Trial Alternative Designs 53

1	Introduction	53
2	Zone Models	54
2.1	Basic Concepts	54
2.2	Model Assumptions	55
2.3	Fires	55
2.4	Heat Transfer	55
2.5	Vent Flow	56
2.6	Plumes and Layers.....	56
2.7	Species Concentrations and Depositions	56
2.8	Predictive Equations.....	57
2.9	Limitations of Zone models.....	58
2.10	Current Available Models	58
2.11	Model Selection.....	60
3	Field Models.....	61
3.1	Basic Concepts	61
3.2	Model Requirements	61
3.3	Boundary and Initial Conditions.....	64
3.4	Current Available Models	65
3.5	Limitations of Field Models	66
3.6	Comparisons between Field Models and Zone Models.....	66
4	Other Special-purpose Programs	67
4.1	Egress Models.....	67
4.2	Smoke Control Models	68
4.3	Fire Endurance Models	68
4.4	Fire Detection Models	70
4.5	Fire Suppression Models.....	70
4.6	Fire Models from NIST	70
5	References.....	71

FIGURE 1	Control Volumes Selected in Zone Modeling.....	54
----------	--	----

APPENDIX 7 Developing Performance-based Criteria 73

1	Effects of Life Safety Criteria	73
1.1	Effects of Toxicity	73
1.2	Effects of Smoke	74
1.3	Effects of Radiant Heat.....	74
1.4	Egress Analysis.....	74
1.5	Effects of Fire Extinguishing Agents on Occupants.....	74
2	Establishing Performance-based Criteria for Life Safety	75
2.1	Heat.....	75
2.2	Visibility	75

2.3	Egress	75
2.4	Toxicity	76
2.5	Performance-based Criteria	76
3	Non-life Safety Criteria	76
3.1	Thermal Effects	76
3.2	Fire Spreads	76
3.3	Smoke Damage	76
3.4	Fire Barrier Damage and Structural Integrity	77
3.5	Damage to Exposed Properties	77
3.6	Damage to the Environment	77
4	References	77

APPENDIX 8 Alternative Design and Example Analysis – Arrangements for Containership Cargo Spaces 79

Introduction	79
Goals of Design	79
Objectives of Design	80
Rule Requirements of Carbon Dioxide Systems	80
Performance Criteria	81
Trial Alternative Design and Arrangements	81
Identification of Fire Hazards	82
1. Sources of hazards:	82
2. Consequence	82
3. Mitigation	82
Specification of Design Fire Scenarios	82
Characteristics of fires	82
Geometry	83
Quantity of Carbon Dioxide Extinguishing Media	85
a. SOLAS Requirement	85
b. IMO FP 47/WP.6.2	85
Discharge Simulation	85
Discharge Rates	85
Computational Tool	86
Input Parameters	86
Quantitative Results	86
Average Volumetric Concentrations of Carbon Dioxide	87
Evaluation with Fires Inside the Cargo Hold	90
Leakage of CO ₂ through Openings during Discharge	91
Minimum Amount of Carbon Dioxide in Multiple Discharging Systems	93
Sensitivity, Uncertainty and Limitations of Numerical Modeling	94
Conclusions	94
References	95

FIGURE 1	Cargo Hold Fully Loaded with Containers	84
FIGURE 2	Hatch Cover Opening and CO2 Nozzles at Tops	84
FIGURE 3	CO ₂ Percent Concentrations in a Fully Loaded Cargo	87
FIGURE 4	CO ₂ Percent Concentrations in Effective Spaces	88
FIGURE 5	CO ₂ Percent at 120 Seconds in Isometric View in Performance-based Design (test # Fullbb)	88
FIGURE 6	CO ₂ Percent at 120 Seconds in Aft View in Performance-based Design (test # Fullbb)	89
FIGURE 7	Detail Flow at the Corners of Containers	89
FIGURE 8	Temperature at Corners of Container Fire	90
FIGURE 9	CO ₂ Concentration in a Design Fire Scenario	91
FIGURE 10	Loss of CO ₂	92
FIGURE 11	Loss Rates of CO ₂	92
FIGURE 12	Minimum CO ₂ Percent Concentrations	93

SECTION 1 Application

1

These Guidance Notes are based on MSC/Circ. 1002, “*Guidelines on Alternative Design and Arrangements for Fire Safety*”. They incorporate the entire contents of MSC/Circ. 1002, and are developed for providing additional explanatory materials and a workable example for fire safety design and analysis.

2

These Guidance Notes are intended to outline the methodology for the engineering analysis required by SOLAS regulation II-2/17, “Alternative design and arrangements”, applying to a specific fire safety system, design or arrangements for which the approval of an alternative design deviating from the prescriptive requirements of SOLAS chapter II-2 is sought.

3

These Guidance Notes are not intended to be applied to the type approval of individual materials and components.

4

These Guidance Notes are not intended to serve as a stand-alone document, but should be used in conjunction with the fire safety engineering design guides and other literature, examples of which are referenced in Section 3 of these Guidance Notes.

5

For the application of these Guidance Notes to be successful, all interested parties, including the Administration or its designated representative, Owners, operators, designers and classification societies, should be in continuous communication from the onset of a specific proposal to utilize these guidelines. This approach usually requires significantly more time in calculation and documentation than a typical regulatory prescribed design because of increased engineering rigor. The potential benefits include more options, cost effective designs for unique applications and an improved knowledge of loss potential.

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SECTION 2 Definitions

For the purposes of these Guidance Notes, the following definitions apply:

- i) *Alternative Design and Arrangements* means fire safety measures which deviate from the prescriptive requirement(s) of SOLAS chapter II-2, but are suitable to satisfy the fire safety objective(s) and the functional requirements of that chapter. The term includes a wide range of measures, including alternative shipboard structures and systems based on novel or unique designs, as well as traditional shipboard structures and systems that are installed in alternative arrangements or configurations.
- ii) *Design Fire* means an engineering description of the development and spread of fire for use in a design fire scenario. Design fire curves may be described in terms of heat release rate versus time.
- iii) *Design Fire Scenario* means a set of conditions that defines the fire development and the spread of fire within and through vessel space(s) and describes factors such as ventilation conditions, ignition sources, arrangement and quantity of combustible materials and fire load accounting for the effects of fire detection, fire protection, fire control and suppression and fire mitigation measures.
- iv) *Functional Requirements* explain in general terms what function the vessel should provide to meet the fire safety objectives of SOLAS.
- v) *Performance Criteria* are measurable quantities stated in engineering terms to be used to judge the adequacy of trial designs.
- vi) *Prescriptive-based Design* or *Prescriptive Design* means a design of fire safety measures which comply with the prescriptive regulatory requirements set out in parts B, C, D, E or G of SOLAS chapter II-2.
- vii) *Safety Margin* means adjustments made to compensate for uncertainties in the methods and assumptions used to evaluate the alternative design, e.g., in the determination of performance criteria or in the engineering models used to assess the consequences of fire.
- viii) *Sensitivity Analysis* means an analysis to determine the effect of changes in individual input parameters on the results of a given model or calculation method.
- ix) *SOLAS* means the International Convention for the Safety of Life at Sea, 1974, as amended.

In addition to the above definitions, the following definitions shall also apply:

- x) *Crew Member* means any person onboard a vessel, including the Master, who is not a passenger.
- xi) *Deterministic Analysis* means a methodology based on physical relationships derived from scientific theories and empirical results that for a given set of initial conditions will always produce the same results of prediction. In a deterministic analysis, a single set of input data will determine a specific set of output predictions.

- xii) *Fire Model* is a physical or mathematical procedure that incorporates engineering and scientific principles in the analysis of fire and fire effects to simulate or predict fire characteristics and conditions of the fire environment.
- xiii) *Fire Safety Objectives* mean the descriptions of the performance benchmarks in SOLAS Chapter II-2/Regulation 2 against which the predicted performance of a design is evaluated.
- xiv) *Hazard* means a possible source of danger that can initiate or cause undesirable consequences if uncontrolled.
- xv) *Model Evaluation* means the process of quantifying the accuracy of chosen results from a model when applied for a specific use.
- xvi) *Model Validation* means the process of determining the correctness of the assumptions and governing equations implemented in a model when applied to the entire class of problems addressed by the model.
- xvii) *Model Verification* means the process of determining the correctness of the solution of the system of governing equations in a model. With this definition, verification does not imply the solution of the correct set of governing equations, only that the given set of equations is solved correctly.
- xviii) *Passenger* is every person other than the Master and the members of the crew or other persons employed or engaged in any capacity onboard a vessel for the business of that vessel.
- xix) *Probability* means the likelihood that a given event will occur. Statistically, this is the number of actual occurrences of a specific event divided by the total number of possible occurrences. Probabilities are inherently dimensionless and expressed as a number between zero and one, inclusive.
- xx) *Probabilistic Analysis* means an evaluation of the fire losses and fire consequences, which includes consideration of the likelihood of different fire scenarios and the inputs that define those fire scenarios.
- xxi) *Risk* means the product of the potential consequences and the expected frequency of occurrence in the classic engineering sense. Consequences might include occupant death, monetary loss, business interruption, or environmental damage. The frequency of occurrence could be an estimate of how often the projected loss might occur.
- xxii) *Stakeholder* means the one who has a share or an interest in an enterprise, specifically, an individual (or a representative) interested in the successful completion of a project. Reasons for having an interest in the successful completion of a project might be financial or safety related.
- xxiii) *Trial Design* means a fire protection system design that is intended to achieve the stated fire safety goals and that is expressed in terms that make the assessment of these achievements possible.

SECTION **3 Engineering Analysis**

1 Process of Alternative Design and Arrangements

The process used to show that the alternative design and arrangements provides the equivalent level of safety to the prescriptive requirements of SOLAS chapter II-2 should follow an established approach to fire safety design. This approach should be based on sound fire science and engineering practice incorporating widely accepted methods, empirical data, calculations, correlations and computer models as contained in engineering textbooks and technical literature.

2 Examples of Acceptable Approaches

Two examples of acceptable approaches to fire safety engineering are listed below:

- i) *The SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Buildings*, Society of Fire Protection Engineers and National Fire Protection Association, 1999.
- ii) ISO/TR 13387-1 through 13387-8, *“Fire safety engineering”*, International Standards Organization, 1999.

Other fire safety engineering approaches recognized by the Administration may be used. See Appendix 3 for guidance and a list of additional technical literature.

3 Phases of Process

The process of the alternative design and arrangements consists of two phases: preliminary analysis and quantitative analysis. The objective of the preliminary analysis is to review and agree upon the scope of the design proposal, identify potential fire hazards, define performance criteria and specify representative fire scenarios which are suitable for detailed analysis and quantification.

The objective of the quantitative analysis is to demonstrate, using standard tools and methodologies, that the vessel design meets the performance criteria agreed to in the preliminary analysis. The quantitative analysis should be based on both probabilistic and deterministic methods, including engineering calculations, computer modeling, Failure Modes and Effects Analysis, event trees and scientific fire tests. The following sections provide more detail regarding completion of the equivalency process and the level of documentation that is expected for equivalency determinations.

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SECTION 4 Design Team

1 General Requirements

A design team acceptable to the Administration should be established by the Owner, builder or designer and may include, as the alternative design and arrangements demand, a representative of the Owner, builder or designer, and expert(s) having the necessary knowledge and experience in fire safety, design, and/or operation as necessary for the specific evaluation at hand. Other members may include marine surveyors, vessel operators, safety engineers, equipment manufacturers, human factors experts, naval architects and marine engineers.

2 Qualifications

The level of expertise that individuals should have to participate in the team may vary depending on the complexity of the alternative design and arrangements for which approval is sought. Since the evaluation, regardless of complexity, will have some effect on fire safety, at least one expert with knowledge and experience in fire safety should be included as a member of the team.

3 Responsibility of Design Team

The design team should:

- i) Appoint a coordinator serving as the primary contact.
- ii) Communicate with the Administration for advice on the acceptability of the engineering analysis of the alternative design and arrangements throughout the entire process.
- iii) Determine the safety margin at the outset of the design process and review and adjust it as necessary during the analysis.
- iv) Conduct a preliminary analysis to develop the conceptual design in qualitative terms. This includes a clear definition of the scope of the alternative design and arrangements and the regulations which affect the design; a clear understanding of the objectives and functional requirements of the regulations; the development of fire scenarios and trial alternative designs. This portion of the process is documented in the form of a report that is reviewed and agreed upon by all interested parties and submitted to the Administration before the quantitative portion of the analysis is started.
- v) Conduct a quantitative analysis to evaluate possible trial alternative designs using quantitative engineering analysis. This consists of the specification of design fires, development of performance criteria based upon the performance of an acceptable prescriptive design and evaluation of the trial alternative designs against the agreed performance criteria. From this step, the final alternative design and arrangements are selected and the entire quantitative analysis is documented in a report.

- vi) Prepare documentation, specifications and a life-cycle maintenance program. The alternative design and arrangements should be clearly documented, approved by the Administration, and a comprehensive report describing the alternative design and arrangements and required maintenance program should be kept onboard the vessel. An operations and maintenance manual should be developed for this purpose. The manual should include an outline of the design conditions that should be maintained over the life of the vessel to ensure compliance with the approved design.

4 Setting the Comparison

The fire safety objectives in SOLAS regulation II-2/2 and the purpose statements listed at the beginning of each individual regulation in chapter II-2 should be used to provide the basis for comparison of the alternative design and arrangements to the prescriptive regulations.

SECTION **5 Preliminary Analysis to Qualitative Terms**

1 Definitions of Scope

The preliminary analysis may begin with a concept review meeting between the Administration and the design team. Depending upon the scope and the level of innovation of the equivalency, such meetings may need to be undertaken at a very early stage to agree on the project's scope. Items to be agreed upon may include a definition of the project scope, level of analysis necessary for this project, and fire safety goals and objectives that the proposed design should meet.

Although much of the information required for the preliminary analysis, as described in Subsection 5/4, may not be known, the design team should be prepared to present a proposed text for such a report at this concept review meeting. The purpose of such a meeting is to achieve agreement on the scope of the proposed equivalency and not for the designer to seek out the Administration's opinion of what they need to do.

1.1 Contents of Scope

1.1.1 Elements of Project Scope

The purpose of this stage is to thoroughly define the boundaries of the problem for the proposed design.

The vessel, vessel system(s), component(s), space(s) and/or equipment subject to the analysis should be thoroughly defined. This includes the vessel or system(s) representing both the alternative design and arrangements and the regulatory prescribed design. Depending on the extent of the desired deviation from prescriptive requirements, some of the information that may be required includes: detailed vessel plans, drawings, equipment information and drawings, fire test data and analysis results, vessel operating characteristics and conditions of operation, operating and maintenance procedures, material properties, etc. Accordingly, the project scope definition must, at a minimum, contain all of the relevant information required by Chapter 4 of the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Building*.

This stage of the process should be started during the earliest stages of the design conception, i.e., at the first point at which the Owner or naval architect acknowledges that an alternative design or arrangements will be necessary. This stage should also be the opportunity for the naval architect or Owner to arrange the concept review meeting to discuss the scope of the alternative design or arrangements with the Administration. If a basic evaluation is required, then it is likely that all of the project definition can occur during the initial meeting.

1.1.2 Defining Goals

Once the project scope has been defined and agreed upon, the design team should identify and agree upon the fire safety goals and objectives. Goals are identified through discussions with the stakeholders and a review of background materials. The following list presents four interrelated fundamental goals for fire safety:

- i) Providing life safety for passengers and vessel crews. Minimize fire-related injuries and prevent undue loss of life.
- ii) Protecting property. Minimize damage to the property from fire.
- iii) Providing for continuity of operations. Protect the organization's ongoing mission, product or operating capability. Minimize undue loss of operations and business-related revenue due to fire-related damage.
- iv) Limiting the environmental impact.

Chapter 5 of the SFPE Guide contains general guidelines for defining the fire safety goals. A goal is normally defined in broad terms by the stakeholders. Section 5, Table 1 provides examples of different goals, which the design teams should understand when conducting a performance-based design.

TABLE 1
Examples of Fire Safety Goals

Fundamental goals • Minimize fire-related injuries and prevent loss of life • Minimize fire-related damage to the vessel, its structures and fire integrity • Minimize loss of vessel operations and business-related revenue to fire-related damage • Limit the environmental impact of the fire and fire protection measures
Other possible goals • Provide sufficient training and awareness to ensure the safety of the crews and passengers • Reduce shipbuilding cost while maintaining adequate life safety measures • Maximize the flexibility of design and innovation

While the stakeholders might share the same global goals, the engineer must understand that the priority and relative weight might vary among stakeholders. Further differences might occur when defining objectives and performance criteria.

1.1.3 Defining Objectives

Once the fire protection goals have been established and agreed to, the fire safety objectives to meet the goals must be defined. SOLAS II-2/Regulation 2 includes a statement of fire safety objectives and the functional requirements to achieve those objectives.

It is recommended that these goals and objectives be the foundation for developing the performance criteria that are specific to the proposal of alternative design and arrangements.

1.2 Documenting Regulations

The regulations affecting the proposed alternative design and arrangements, along with their functional requirements, should be clearly understood and documented in the preliminary analysis report (see Subsection 5/4). This should form the basis for the comparative analysis referred to in Subsection 6/4.

2 Development of Fire Scenarios

2.1 General

Fire scenarios should provide the basis for analysis and trial alternative design evaluation and, therefore, are the backbone of the alternative design process. Proper fire scenario development is essential and, depending on the extent of deviation from the prescribed design, may require a significant amount of time and resources.

(For each of the identified fire hazards, a range of fire scenarios should be developed. The use of event trees is recommended to systematically determine all of the possible fire scenarios resulting from a specific hazard. Because the alternative design approach is based on a comparison against the regulatory prescribed design, the quantification can often be simplified. In many cases, it may only be necessary to analyze one or two scenarios if this will provide enough information to evaluate the level of safety of the alternative design and arrangements against the agreed performance design. Appendix 4 provides a minimum design fire scenario that should be considered.)

This process can be broken down into four areas:

- i) Identification of fire hazards
- ii) Enumeration of fire hazards
- iii) Selection of fire hazards
- iv) Specification of design fire scenarios

2.1.1 Identification of Fire Hazards

This step is crucial in the fire scenario development process as well as in the entire alternative design methodology. If a fire hazard or incident is omitted, then it will not be considered in the analysis and the resulting final design may be inadequate. Fire hazards may be identified using historical and statistical data, expert opinion and experience and hazard evaluation procedures. There are many hazard evaluation procedures available to help identify the fire hazards including HAZOP, PHA, FMEA, “what-if”, etc. Further details on the use of these procedures specific to identifying possible fire hazards is contained in other references including the *SFPE Engineering Guide to Performance Based Fire Protection Analysis and Design of Buildings*, and the *SFPE Handbook of Fire Protection Engineering*. As a minimum, the following conditions and characteristics should be identified and considered:

- i) *Pre-fire situations.* Vessel, platform, compartment, fuel load, environmental conditions
- ii) *Ignition sources.* Temperature, energy, time and area of contact with potential fuels
- iii) *Initial fuels.* State (solid, liquid, gas, vapor, spray), surface area to mass ratio, rate of heat release
- iv) *Secondary fuels.* Proximity to initial fuels, amount, distribution
- v) *Extension potential.* Beyond compartment, structure, area (if in open)

- vi) *Target locations.* Note target items or areas associated with the performance parameters
- vii) *Critical factors.* Ventilation, environment, operational, time of day, etc.
- viii) *Relevant statistical data.* Past fire history, probability of failure, frequency and severity rates, etc.

More details of characterizing design fire scenarios can be found in Chapter 8 of the *SFPE Engineering Guide to Performance-Based Fire Protection Analysis and Design of Building*.

2.1.2 Enumeration of Fire Hazards

All of the fire hazards identified above should be grouped into one of three incident classes: localized, major or catastrophic. A localized incident consists of a fire with a localized effect zone, limited to a specific area. A major incident consists of a fire with a medium effect zone, limited to the boundaries of the vessel. A catastrophic incident consists of a fire with a large effect zone, beyond the vessel and affecting surrounding vessels or communities. In the majority of cases, only localized and/or major fire incidents need to be considered. Examples where the catastrophic incident class may be considered would include transport and/or offshore production of petroleum products or other hazardous materials where the incident effect zone is very likely to be beyond the vessel vicinity. The fire hazards should be tabulated for future selection of a certain number of each of the incident classes.

2.1.3 Selection of Fire Hazards

The number and type of fire hazards that should be selected for the quantitative analysis is dependent on the complexity of the trial alternative design and arrangements. All of the fire hazards identified should be reviewed for selection of a range of incidents. In determining the selection, frequency of occurrence does not need to be fully quantified, but it can be utilized in a qualitative sense. The selection process should identify a range of incidents which cover the largest and most probable range of enumerated fire hazards. Because the engineering evaluation relies on a comparison of the proposed alternative design and arrangements with prescriptive designs, demonstration of equivalent performance during the major incidents should adequately demonstrate the design's equivalence for all lesser incidents and provide the commensurate level of safety. In selecting the fire hazards, it is possible to lose perspective and to begin selecting highly unlikely or inconsequential hazards. Care should be taken to select the most appropriate incidents for inclusion in the selected range of incidents.

2.1.4 Specification of Design Fire Scenarios

Based on the fire hazards selected, the fire scenarios to be used in the quantitative analysis should be clearly documented. The specification should include a qualitative description of the design fire (e.g., ignition source, fuel first ignited, location, etc.), description of the vessel, compartment of origin, fire protection systems installed, number of occupants, physical and mental status of occupants and available means of escape. The fire scenarios should consider possible future changes to the fire load and ventilation system in the affected areas. The design fire(s) will be characterized in more detail during the quantitative analysis for each trial alternative design. Appendix 4 provides the explanatory materials for design fire scenarios, the methodology of identifying design fire scenarios and some examples of design fire scenarios in NFPA 101.

3 Development of Trial Alternative Designs

At this point in the analysis, one or more trial alternative designs should be developed so that they can be compared against the developed performance criteria. Trial alternative designs are the fire protection strategies developed by the design team that are intended to meet the objectives, functional statements and performance requirements. The trial alternative design should also take into consideration the importance of human factors, operations and management as reflected in part E of SOLAS chapter II-2. It should be recognized that well-defined operations and management procedures might play a large part in increasing the overall level of safety. Appendix 5 provides the explanatory details to assist in developing alternative designs by understanding what the objectives and functional statements are, as well as the performance requirements, and looking at various individual or combinations of subsystems that will allow one to achieve the performance requirements.

Under certain circumstances, such as designing an alternative or innovative fire fighting system, the trial alternative design should be subject to a test conducted by an accredited independent third party (i.e., test facility or laboratory) or the group undertaking the actual alternative design. The test could be modeled or full-scaled experiment; it could be theoretical or practical. If the test is done by computer modeling, further testing may be required. Furthermore, if a practical test is done to the pre-agreed criteria, then the test house should publish a report and conclusions. The test results of trial alternative design should be documented in a report published by the above testing parties. The purpose of the report is to provide an open and available set of conclusive results.

The test report should include all of the data, wherein the test results of the trial alternative design as achieved or obtained are plotted or indicated in a comparative manner in conjunction with the performance criteria, and the results of which are not mathematically scaled from a test of different proportions (i.e., smaller or alternative fire proportions rather than compartment proportions). For example, very often the area or volume is scaled but the fire is not, and then the actual test (physical) being conducted is not indicative of the same results since the proportions and ratios are in fact a little different.

4 Preliminary Analysis Report

4.1 Contents of Report

A report of the preliminary analysis should include clear documentation of all steps taken to this point, including identification of the design team, their qualifications, the scope of the alternative design analysis, the functional requirements to be met, the description of the fire scenarios and trial alternative designs selected for the quantitative analysis.

4.2 Submittal of Report

The preliminary analysis report should be submitted to the Administration for formal review and agreement prior to beginning the quantitative analysis. The report may also be submitted to the port State for informational purposes, if the intended calling ports are known during the design stage. The key results of the preliminary analysis should include:

- i) A secured agreement from all parties to the design objectives and engineering evaluation
- ii) Specified design fire scenario(s) acceptable to all parties
- iii) Trial alternative design(s) acceptable to all parties

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SECTION 6 Quantitative Analysis

1 General

The quantitative analysis is the most labor-intensive from a fire safety engineering standpoint. It consists of quantifying the design fire scenarios, developing the performance criteria, verifying the acceptability of the selected safety margins and evaluating the performance of trial alternative designs against the prescriptive performance criteria.

1.1 Scope

The quantification of the design fire scenarios may include calculating the effects of fire detection, alarm and suppression methods, generating time lines from initiation of the fire until control or evacuation, and estimating consequences in terms of fire growth rate, heat fluxes, heat release rates, flame heights, smoke and toxic gas generation, etc. This information will then be utilized to evaluate the trial alternative designs selected during the preliminary analysis.

1.2 Risk Assessment

Risk assessment may play an important role in this process. It should be recognized that risk cannot ever be completely eliminated. Throughout the entire performance-based design process, this fact should be kept in mind. The purpose of performance design is not to build a fail-safe design, but to specify a design with reasonable confidence that it will perform its intended function(s) when necessary and in a manner equivalent to or better than the prescriptive fire safety requirements of SOLAS chapter II-2.

2 Quantification of Design Fire Scenarios

2.1 Choosing Models for Quantification

After choosing an appropriate range of fire incidents, quantification of the fires should be accomplished for each of the incidents. Quantification will require specification of all factors that may affect the type and extent of the fire hazard. The fire scenarios should consider possible future changes to the fire load and ventilation system in the affected areas. This may include calculation of heat release rate curves, flame height, length and tilt, radiant, conductive and convective heat fluxes, smoke production rate, pool fire size, duration, timelines, etc. References on suggested example correlations and models that may be of use are listed in Appendix 3.

Models for quantification of fire scenarios shall be chosen based upon an appropriate evaluation and verification process. The methodology for evaluating the predictive capability of fire models by which the process can be classified into four areas of evaluation as described in ASTM E 1355-97 is recommended:

2.1.1 Model and Scenario Definition

Sufficient documentation of calculation models, including computer software, is absolutely necessary to assess the adequacy of the scientific and technical basis of the models and the accuracy of computational procedures. Also, adequate documentation will help prevent the unintentional misuse of fire models.

Scenario definition provides a complete description of the scenarios or phenomena of interest in the evaluation to facilitate appropriate application of the model, to aid in developing realistic inputs for the model, and criteria for judging the results of the evaluation.

2.1.2 Theoretical Basis for the Model

An independent review of the underlying physics and chemistry inherent in a model ensures appropriate application of sub-models which have been combined to produce the overall model. This review should include the assessment of the completeness of the documentation, particularly with regard to the assumptions and approximations, and the assessment of whether there is sufficient scientific evidence in the open scientific literature to justify the approaches and assumptions being used. Empirical or reference data used for constants and default values in the code should also be assessed for accuracy and applicability in the context of the model.

2.1.3 Mathematical and Numerical Robustness

The computer implementation of the model should be checked to ensure such implementation matches the stated documentation. The analyses which can be performed include analytical tests, code checking and numerical tests.

Many fire problems involve the interaction of different physical processes, such as the chemical or thermal processes and the mechanical response. Time scales associated with the processes may be substantially different, which can easily cause numerical difficulties. Such problems are called stiff. Some numerical methods have difficulty with stiff problems since they slavishly follow the rapid changes even when they are less important than the general trend in the solution. Special algorithms should be devised for those cases with stiff problems.

2.1.4 Model Uncertainty and Accuracy of the Model

2.1.4(a) Model Uncertainty. Even deterministic models rely on inputs often based on experimental measurements, empirical correlations or estimates, made by engineering judgment. Uncertainties in the model inputs can lead to corresponding uncertainties in the model outputs. Sensitivity analysis is used to quantify these uncertainties in the model outputs based upon known or estimated uncertainties in model inputs. The purpose of conducting a sensitivity analysis is to assess the extent to which uncertainty in the model inputs is manifested to become uncertainty in the result of interest from the model.

2.1.4(b) Experimental Uncertainty. In general, the result of measurement is only the result of an approximation or estimate of the specific quantity subject to measurement, and thus the result is complete only when accompanied by a quantitative statement of uncertainty.

2.1.4(c) Model Evaluation. A model should be assessed for a specific use in terms of its quantitative ability to predict outcomes such as fire growth and spread, rate of flame spread, fire resistance, fire hazard typified by available egress time, tenability, response of active and passive fire protection, and some other property damages, etc. As a result, a model may be evaluated by comparisons with standard tests, full-scaled tests conducted specifically for the chosen evaluation, previously published full-scaled test data, documented fire experience, proven benchmark models, etc.

Obtaining accurate estimates of fire behavior using predictive fire models involves ensuring correct model inputs appropriate to the scenarios to be modeled, correct selection of a model appropriate to the scenarios to be modeled, correct calculations by the model chosen and correct interpretation of the results of the model calculation. Evaluation of a specific scenario with different levels of knowledge of the expected results of the calculation addresses these multiple sources of potential error.

2.1.5 Choosing Tools for Trial Design Scenarios

It should be noted that when using any of these or other tools, the limitations and assumptions of these models should be well understood and documented. This becomes very important when deciding on and applying safety margins. Documentation of the alternative design should explicitly identify the fire models used in the analysis and their applicability. Reference to the literature alone should not be considered as adequate documentation. A summary of the deterministic fire models is provided in Appendix 6. The general procedure for specifying design fires includes fire scenario development completed during the preliminary analysis, timeline analysis and consequence estimation, which are detailed below.

2.2 Developing Fire Scenarios

For each of the identified fire hazards, a range of fire scenarios should be developed. Because the alternative design approach is based on a comparison against the regulatory prescribed design, the quantification can often be simplified. In many cases, it may only be necessary to analyze one or two scenarios if this provides enough information to evaluate the level of safety of the alternative design and arrangements against the required prescriptive design.

2.3 Description of Fire Scenarios

A timeline should be developed for each of the fire scenarios beginning with fire initiation. Timelines should include one or more of the following: ignition, established burning, fire detection, fire alarm, fire suppression/control system activation, personnel response, fire control, escape times (to assembly stations, evacuation stations and lifeboats, as necessary), manual fire response, untenable conditions, etc. The timeline should include fire size throughout the scenario, as determined by using the various correlations, models and fire data from the literature or actual fire tests.

2.4 Consequences of Fire Scenarios

Consequences of various fire scenarios should be quantified in fire engineering terms. This can be accomplished by using existing correlations and calculation procedures for determining fire characteristics such as heat release rate curves, flame height, length and tilt, radiant, conductive and convective heat fluxes, etc. In certain cases, live fire testing and experimentation may be necessary to properly predict the fire characteristics. Regardless of the calculation procedures utilized, a sensitivity analysis should be conducted to determine the effects of the uncertainties and limitations of the input parameters.

3 Development of Performance Criteria

3.1 General

Performance criteria are quantitative expressions of the fire safety objectives and functional requirements of the SOLAS regulations. The required performance of the trial alternative designs is specified numerically in the form of performance criteria. Performance criteria may include tenability limits such as smoke obscuration, temperature, height of the smoke and hot gas layer in a compartment, evacuation time or other criteria necessary to ensure successful alternative design and arrangements.

3.2 Performance Criteria Based Directly on SOLAS Chapter II-2

Each of the regulations in SOLAS chapter II-2 state the purpose of the regulation and the functional requirements that the regulation meets. Compliance with the prescriptive regulations is one way to meet the stated functional requirements. In some cases, the performance criteria for the alternative design and arrangements should be determined by a direct interpretation of the regulations, taking into consideration the fire safety objectives, the purpose statements and the functional requirements of the regulations. The following example is an illustration of this:

“Example of a performance criterion drawn directly from the regulations in SOLAS chapter II-2:

Assume that a design team is developing performance criteria for preventing fire spread through a bulkhead separating a galley from an accommodation space. They are seeking a numerical form for this criteria.

(e.1) Regulation II-2/2 contains the fire safety objective “to contain, control, and suppress fire and explosion in their compartment of origin.”

(e.2) One of the functional requirements in which this objective is manifest is “separation of accommodation spaces from the remainder of the ship by thermal and structural boundaries.”

(e.3) Regulation II-2/9 contains the prescriptive requirements to achieve this functional requirement; in particular it requires an “A-60” class boundary between areas of high fire risk (like a machinery space or galley) and accommodation spaces.

(e.4) Regulation II-2/3 contains the definition of an “A” class division, which includes the maximum temperature rise criteria of 180°C at any one point, after a 60 minute fire exposure.

(e.5) Therefore, one possible performance criterion for this analysis is that “no point on the other side of the bulkhead shall rise more than 180°C above ambient temperature during a 60 minute fire exposure.”

3.3 Performance Criteria Developed from a Commonly Used Acceptable Prescriptive Design

If the performance criteria for the alternative design and arrangements cannot be determined directly from the prescriptive regulations because of novel or unique features, they may be developed from a quantitative evaluation of the intended performance of a commonly used acceptable prescriptive design, provided that an equivalent level of fire safety is maintained. This is a useful method for developing performance criteria where it is difficult to quantify the desired performance in terms of absolute values. By stating the performance criteria in terms of the performance of a regulatory design, it can be inherently assumed that the features incorporated in the regulatory design provide an overall acceptable level of safety.

Comparative performance criteria should be specified in terms of a comparison to a similar prescriptive design. Further, since the alternative design will invariably have some difference from the regulatory design, the criteria should also address cases when the regulatory design does not provide a sufficient level of performance. As an example: “*The alternative design shall provide the lesser of: the evacuation time for a vessel built to the requirements of SOLAS II-2/13; or the minimum evacuation time required by the assumed design fires for the proposed design*”. When the performance criteria are determined through comparative analysis, it will be necessary for the design team to quantify the performance of both the alternative design and the regulatory prescribed design during the quantitative analysis.

3.4 Specific Performance Criteria and Safety Margins

Before evaluating the prescriptive design, the design team should agree on what specific performance criteria and safety margins should be established. Depending on the prescriptive requirements to which the approval of alternative design or arrangements is sought, these performance criteria could fall within one or more of the following areas:

3.4.1 Life Safety Criteria

These criteria address the survivability of passengers and crew and may represent the effects of heat, smoke, toxicity, reduced visibility and evacuation time.

3.4.2 Criteria for Damage to Vessel Structure and Related Systems

These criteria address the impact that fire and its effluents might have on the vessel structure, mechanical systems, electrical systems, fire protection systems, evacuation systems, propulsion and maneuverability, etc. These criteria may represent thermal effects, fire spread, smoke damage, fire barrier damage, degradation of structural integrity, etc.

3.4.3 Criteria for Damage to the Environment

These criteria address the impact of heat, smoke and released pollutants on the atmosphere and marine environment.

Appendix 7 provides a description of the effects of life and non-life safety criteria.

3.5 Impact on Areas not Specifically Part of the Alternative Design

The design team should consider the impact that one particular performance criterion might have on other areas that might not be specifically part of the alternative design. For example, the failure of a fire barrier may not only affect the life safety of passengers and crew in the adjacent space, but it may result in structural failure, exposure of essential equipment to heat and smoke and the involvement of additional fuel in the fire.

3.6 Evaluation

Once all of the performance criteria have been established, the design team can then proceed with the evaluation of the trial alternative designs (see Subsection 6/4).

4 Evaluation of Trial Alternative Designs

4.1 Process Flowchart

All of the data and information generated during the preliminary analysis and specification of design fires should serve as input to the evaluation process. The evaluation process may differ depending on the level of evaluation necessary (based on the scope defined during the preliminary analysis), but should generally follow the process illustrated in Section 6, Figure 1.

4.2 Analysis of Trial Design

Each selected trial alternative design should be analyzed against the selected design fire scenarios to demonstrate that it meets the performance criteria with the agreed safety margin, which in turn demonstrates equivalence to the prescriptive design.

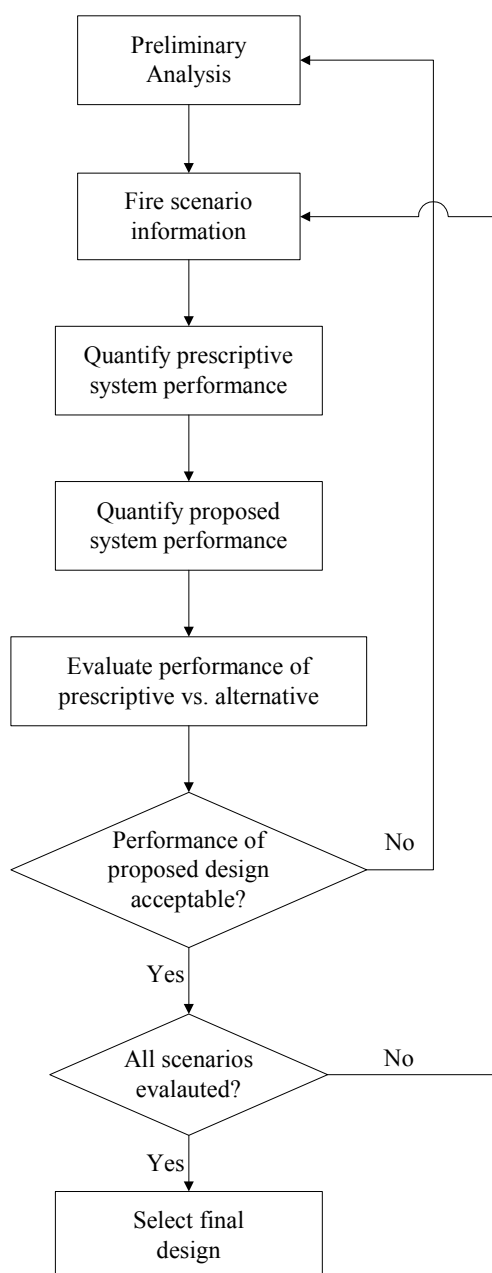
4.3 Level of Engineering Analysis

The level of engineering rigor required in any particular analysis will depend on the level of analysis required to demonstrate equivalency of the proposed alternative design and arrangements to the prescriptive requirements. Obviously, the more components, systems, operations and parts of the vessel that are affected by a particular alternative design, the larger the scope of the analysis.

4.4 Final Alternative Design and Arrangements

The final alternative design and arrangements should be selected from the trial alternative designs that meet the selected performance criteria and safety margins.

FIGURE 1
Alternative Design and Arrangements Process Flowchart



SECTION 7 Documentation

1 Basic Requirements

Because the alternative design process may involve substantial deviation from the regulatory prescribed requirements, the process should be thoroughly documented. This provides a record that will be required if future design changes to the vessel are proposed or the vessel transfers to the flag of another State, and will also provide details and information that may be adapted for use in future designs. The following information should be provided for approval of the alternative design or arrangements:

1.1 Scope of the Analysis or Design

The scope of the analysis or design might include the following:

- i) Design intents (e.g., new construction, renovation or upgrade of an existing facility, or repair of a damaged structure, etc.)
- ii) Project constraints (e.g., effects on other vessel operations, limitations, etc.)
- iii) Stakeholders (vessel owners, flag state, classification society, insurers, design and construction team organization, etc.)
- iv) Project schedules (e.g., length of project)
- v) Applicable regulations (SOLAS, ABS, etc.)

1.2 Description of Alternative Design(s) or Arrangement(s)

Description of the alternative design(s) or arrangements(s), including drawings and specifications:

- i) Qualitative goals of design(s) and arrangement(s), which might include:
 - Protection of life safety (e.g., minimize fire-related injuries, and prevent undue loss of life, etc.)
 - Protection of property (e.g., minimize damage to vessel structure from fire and exposure to and from adjacent spaces)
 - Providing for continuity of operations of vessels due to fires.
- ii) Objectives of design(s) and arrangement(s)
 - Fire safety goals and objectives agreed between the engineers and other stakeholders should be included.
 - The method by which the design objectives are developed, including any uncertainty and safety factors, should be included.
- iii) All drawings of the alternative design(s) or arrangement(s)
- iv) Detailed vessel plans